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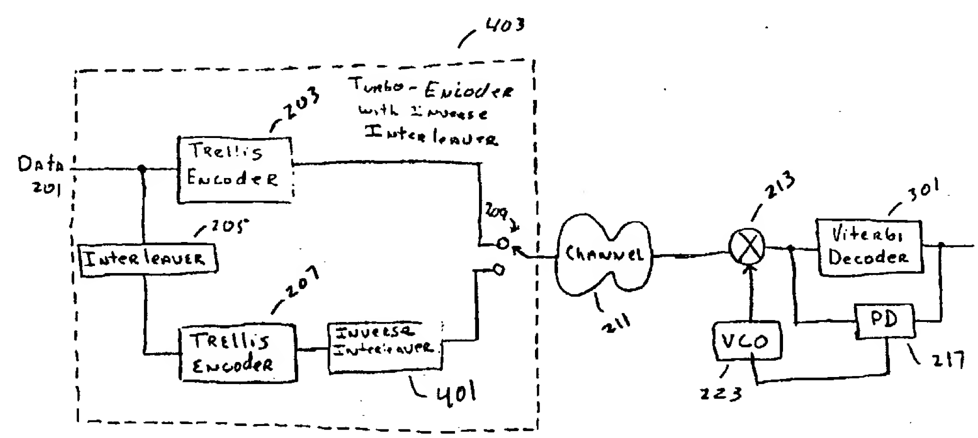
(54) **Title:** VITERBI SLICER FOR TURBO CODES



(57) **Abstract:** A method for synchronizing receivers that received turbo encoded signals to a received signal. Turbo encoding may enable signals to be decoded at a much lower signal to noise ratio than previously practical. A traditional method of synchronizing a receiver to an incoming signal is to use a slicer to determine a received symbol and then to compare the determined symbol to the incoming waveform, in order to adjust the phase of the slicer with respect to the incoming signal. At signal low levels, at which turbo encoded signals may be decoded, this slicing method may be prone to errors that may disrupt the synchronization of the receiver to the incoming signal. By replacing the slicer by a Viterbi decoder with zero traceback (i.e. one which does not consider future values of the signal only past values) a predection as to what the incoming signal is can be made. Because the Viterbi decoder can consider past signal values it can predict the present symbol being received with higher reliability than by using a slicer, which considers only the present value of the incoming signal.

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VITERBI SLICER FOR TURBO CODES

BACKGROUND OF THE INVENTION

As coding technology improves signals can be decoded with lower signal to noise ratios. Decreasing signal levels that can be decoded require receivers that can acquire and track at lower signal levels. There is therefore a need in the art for receiver technology to enable the acquisition and tracking of signals at lower signal levels.

SUMMARY OF THE INVENTION

In one aspect of the present invention, a method of processing signals includes receiving first and second signals each being modulated on a carrier signal, the first signal preceding the second signal in time, multiplying each of the first and second signals with a reference signal having a reference frequency, adjusting the multiplied first signal based on the multiplied first and second signals, comparing the adjusted first signal to the multiplied first signal, and adjusting the reference frequency as a function of the comparison.

In another aspect of the present invention, a receiver includes an oscillator having a reference signal output with a tunable reference frequency, a multiplier to multiply a first signal with the reference signal, and to multiply a second signal, succeeding the first signal in time, with the reference signal, the first and second signals each being modulated on a carrier frequency, a decoder to adjust the multiplied first signal based on the multiplied first and second signals, and a detector to compare the adjusted first signal with the multiplied first signal, the detector being adapted to tune the reference frequency as a function of the comparison.

In yet another aspect of the present invention, a receiver includes an oscillator having a tuning input, a multiplier having a first input to receive a signal, and a second input coupled to the oscillator, the signal comprising a first signal and a second signal succeeding the first signal in time, the first and second signals each being modulated on a carrier frequency, a decoder having an input coupled to the multiplier, and an output, and a detector having a first input coupled to the decoder input, a second input coupled to the decoder output, and an output coupled to the tuning input of the oscillator.

In a further aspect of the present invention, a receiver includes oscillator means for generating a reference signal having a tunable reference frequency, multiplier means for multiplying a first signal with the reference signal, and multiplying a second signal, succeeding the first signal in time, with the reference signal, the first and second signals each being modulated on a carrier frequency, decoder means for adjusting the multiplied first signal based on the multiplied first and second signals, and detector means for comparing the adjusted first signal with the multiplied first signal, the detector means comprises tuning means for tuning the reference frequency as a function of the comparison.

In yet a further aspect of the present invention, a method of processing signals having a

first and second symbol each representing a constellation point, the first symbol preceding the second symbol in time, includes quantizing the first symbol to its nearest constellation point as a function of the first and second signals, comparing the first symbol to the quantized first symbol, and adjusting a reference frequency as a function of the comparison.

In still a further aspect of the present invention, a receiver to receive a signal including first and second symbols each representing a constellation point, the first symbol preceding the second symbol in time, includes a decoder to quantize the first symbol as a function of the first and second symbols, a detector to compare the first symbol to the quantized first symbol, and an oscillator having a tunable output as a function of the comparison.

In another aspect of the present invention, a communications system includes a transmitter to transmit a signal including first and second symbols each representing a constellation point, the first symbol preceding the second symbol in time, and a receiver including a decoder to quantize the first symbol as a function of the first and second symbols, a detector to compare the first symbol to the quantized first symbol, and an oscillator having a tunable output as a function of the comparison.

It is understood that other embodiments of the present invention will become readily apparent to those skilled in the art from the following detailed description, wherein it is shown and described only embodiments of the invention by way of illustration of the best modes contemplated for carrying out the invention. As will be realized, the invention is capable of other and different embodiments and its several details are capable of modification in various other respects, all without departing from the spirit and scope of the present invention. Accordingly, the drawings and detailed description are to be regarded as illustrative in nature and not as restrictive.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features, aspects, and advantages of the present invention will become better understood with regard to the following description, appended claims, and accompanying drawings where:

Figure 1 is a graphical illustration of a prior art communications system.

Figure 2 is a graphical illustration of a communication system in which the coding section comprises a turbo encoder.

Figure 3 is a graphic illustration of a communication system according to an embodiment of the invention.

Figure 4 is a graphic illustration of a communication system according to an embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

Figure 1 is a graphical illustration of a communications system. In Figure 1, data 101 is

provided to an encoder 103. The encoder codes the data and then provides it to a transmitter 105. The transmitter modulates the coded data on a carrier frequency, amplifies the resultant signal and broadcasts it to a relay satellite 107. The relay satellite 107 then rebroadcasts the data transmission to a receiver 109. The received signal is then provided by the receiver 109 to a mixer 113. A voltage controlled oscillator 123 provides a mixer signal to the mixer with the result that the coded signal is translated to a baseband signal. The coded baseband signal comprises the data and the coding added by encoder 103. The transport interface of the signal from (and including) the transmitter 105 to (and including) the receiver 109 is referred to as a channel 111.

The coded data from the multiplier 113 is filtered (filter not shown) and provided to a slicer 115. The slicer 115 extracts symbols from the coded data stream and provides it to a decoder 119. The decoder 119 decodes the symbols and creates a data stream 121. A phase detector 117 compares the symbol found by the slicer 115 with the value input to the slicer. By comparing the signal input to the slicer to the actual symbol found by the slicer in the phase detector 117, the phase detector detects whether the slicing process is leading or lagging the actual symbol value detected within the data stream. The phase detector 117 can then adjust the voltage controlled oscillator 123 to adjust the mixer signal provided to the multiplier 113 to match the carrier signal.

Figure 2 is a graphical illustration of a communication system in which the encoder 103 is replaced by a turbo encoder 200. The turbo encoder 200 accepts data 201. The data is then encoded in a first trellis encoder 203. The data is also interleaved by an interleaver 205 and provided to a second trellis encoder 207. The second trellis encoder 207 may be identical to the first trellis encoder 203, but it may also be different. The outputs of trellis encoders 203 and 207 are then punctured by switch 209. In other words, switch 209 selects between the output of trellis encoder 203 and trellis encoder 207. The punctured output of turbo encoder 200 is then provided to a channel 211.

The signal received from the channel is then coupled into a multiplier 213, and the received signal is mixed with a mixer signal (as provided by the VCO 223), which replicates the carrier signal. The slicer 215 slices the symbols from the data stream, and the phase detector 217 detects the difference between the sliced symbol found at the output of the slicer 215 and the value input to the slicer. The output of the phase detector then adjusts the VCO 223 in order to correct the carrier signal being mixed in multiplier 213. The output of the slicer is then coupled into turbo decoder 219 to decode the turbo encoded data.

Turbo encoder 200 is a parallel concatenated encoder. Parallel concatenated codes ("turbo codes") allow communications systems to operate near the Shannon capacity. However, when operating in this region, the signal to noise ratio may be very low. This low signal to noise ratio (E_S/N_O) can make synchronization with a received signal difficult. If the channel symbol error rate is greater than 1:10 (i.e., one out of ten transmitted signals is decoded incorrectly), a decision

directed loop, such as illustrated in Figure 2 (comprising the slicer 215 and phase detector 217) can fail. In order to improve the accuracy, the slicer 215 may be replaced by a Viterbi decoder as illustrated in Figure 3. Viterbi decoders typically produce the most likely channel symbol based on past data, present data and (depending on trace-back depth) future data. A Viterbi decoder uses the past and future data as well as correlations within the data to produce a current symbol that is more likely to be correct than if only the present data is used (such as with a typical data slicer). In the embodiment illustrated in Figure 3, future data is not available, so the Viterbi decoder 301 will examine past and present data in order to produce a symbol, which is more likely to be accurate than one determined by a slicer mechanism such as illustrated in Figure 2. A Viterbi decoder is more likely to make an accurate decision as to what the symbol being decoded is based on a history of inputs than can a slicer, which makes a decision based on only the present input.

The turbo encoder 200, however, is a parallel concatenated encoder. Turbo encoder 200 comprises two trellis encoders separated by an interleaver 205. Any number of trellis encoders separated by interleavers may be used, but two are shown for sake of simplicity.

The interleaver 205 accepts the data 201 and interleaves or shuffles the data before providing it to the trellis encoder 207. As a result, the data provided by the lower leg of the turbo encoder comprising the trellis encoder 207 is out of sequence and must be resequenced. For this reason, switch 303 is added to the Viterbi decoder 301 so that only the symbols from trellis encoder 203 or trellis encoder 207 are used by the phase detector 217 to adjust the controlled oscillator 223. The delay introduced by interleaver 205 makes it impractical for the Viterbi decoder 301 to use symbols from both sides of the turbo encoder 200 without a buffering and delay mechanism at the input of the Viterbi decoder. Switch 303 will select every other symbol. Either a symbol from trellis encoder 203 will be selected or a symbol from trellis encoder 207 will be selected by switch 303.

Figure 4 is a graphical illustration of a communication system according to an embodiment of the invention. In Figure 4, the turbo encoder 403 has been modified by placing an inverse interleaver in series with trellis encoder 207. The inverse interleaver 401 unscrambles the order of the data which had been scrambled by the interleaver 205, after it has been trellis encoded. By utilizing inverse interleaver 401, every symbol can be used by the Viterbi decoder 301 in order to synchronize the frequency of the VCO 223.

Although a preferred embodiment of the present invention has been described, it should not be construed to limit the scope of the appended claims. Those skilled in the art will understand that various modifications may be made to the described embodiment. Moreover, to those skilled in the various arts, the invention itself herein will suggest solutions to other tasks and adaptations for other applications. It is therefore desired that the present embodiments be considered in all respects as illustrative and not restrictive, reference being made to the appended claims rather than the foregoing description to indicate the scope of the invention.

WHAT IS CLAIMED IS:

1. A method of processing signals, comprising:

receiving first and second signals each being modulated on a carrier signal, the first signal preceding the second signal in time;

multiplying each of the first and second signals with a reference signal having a reference frequency;

adjusting the multiplied first signal based on the multiplied first and second signals;

comparing the adjusted first signal to the multiplied first signal; and

adjusting the reference frequency as a function of the comparison.

2. The method of claim 1 wherein the first and second signals each comprises turbo encoded data.

3. The method of claim 1 wherein the multiplied first and second signals each comprises a baseband signal.

4. The method of claim 1 wherein the adjustment of the multiplied first signal comprises Viterbi decoding the multiplied first signal.

5. The method of claim 1 wherein the comparison of the adjusted first signal with the multiplied first signal comprises detecting a phase difference between the adjusted first signal and the multiplied first signal.

6. The method of claim 5 wherein the adjustment of the reference frequency comprises tuning a voltage controlled oscillator as a function of the phase difference between the adjusted first signal and the multiplied first signal.

7. The method of claim 1 wherein the adjustment of the reference frequency comprises adjusting the reference frequency to be substantially equal to a frequency of the carrier signal.

8. The method of claim 1 wherein the first and second received signals each comprises a symbol representing a constellation point, and wherein the adjustment of the multiplied first signal comprises quantizing the multiplied first signal to its nearest constellation point as a function of the multiplied first and second signals.

9. The method of claim 1 further comprising receiving a third signal between the first and second signals, wherein the adjustment of the multiplied first signal is not based on the received third signal.

10. The method of claim 1 further comprising transmitting signals including the first and second signals, wherein the receiving of the first and second signals comprises receiving the transmitted signals.

11. The method of claim 10 wherein the transmission of the signals comprises turbo encoding the signals before transmission.

12. The method of claim 11 wherein the transmission of the signals comprises interleaving and de-interleaving the turbo encoded signals before transmission.

13. The method of claim 11 wherein the transmission of the signals comprises transmitting a third signal between the first and second signals, a first portion of the signals including the first and second signals being turbo encoded, and a second portion of the signals including the third signal being turbo encoded and interleaved.

14. The method of claim 13 further comprising receiving the transmitted third signal between the transmitted first and second signals, wherein the adjustment of the multiplied first signal is not based on the received third signal.

15. A receiver, comprising:

an oscillator having a reference signal output with a tunable reference frequency;

a multiplier to multiply a first signal with the reference signal, and to multiply a second signal, succeeding the first signal in time, with the reference signal, the first and second signals each being modulated on a carrier frequency;

a decoder to adjust the multiplied first signal based on the multiplied first and second signals; and

a detector to compare the adjusted first signal with the multiplied first signal, the detector being adapted to tune the reference frequency as a function of the comparison.

16. The receiver of claim 15 wherein the oscillator comprises a voltage controlled oscillator.

17. The receiver of claim 15 wherein the decoder comprises a Viterbi decoder.

18. The receiver of claim 17 wherein the Viterbi decoder comprises a zero trace back Viterbi decoder.

19. The receiver of claim 15 wherein the detector comprises a phase detector to compare a phase of the adjusted first signal with a phase of the multiplied first signal, the phase detector being adapted to tune the reference frequency as a function of a difference in phases.

20. The receiver of claim 15 further comprising a switch to prevent a third signal between the first and second signals from being decoded by the decoder.

21. A receiver, comprising

an oscillator having a tuning input;

a multiplier having a first input to receive a signal, and a second input coupled to the oscillator, the signal comprising a first signal and a second signal succeeding the first signal in time, the first and second signals each being modulated on a carrier frequency;

a decoder having an input coupled to the multiplier, and an output; and

a detector having a first input coupled to the decoder input, a second input coupled to the decoder output, and an output coupled to the tuning input of the oscillator.

22. The receiver of claim 21 wherein the oscillator comprises a voltage controlled oscillator.

23. The receiver of claim 21 wherein the decoder comprises a Viterbi decoder.

24. The receiver of claim 23 wherein the Viterbi decoder comprises a zero trace back Viterbi decoder.

25. The receiver of claim 21 wherein the detector comprises a phase detector.

26. The receiver of claim 21 further comprising a switch between the multiplier and the decoder input.

27. A receiver, comprising

oscillator means for generating a reference signal having a tunable reference frequency;

multiplier means for multiplying a first signal with the reference signal, and multiplying a second signal, succeeding the first signal in time, with the reference signal, the first and second signals each being modulated on a carrier frequency;

decoder means for adjusting the multiplied first signal based on the multiplied first and second signals; and

detector means for comparing the adjusted first signal with the multiplied first signal, the detector means comprises tuning means for tuning the reference frequency as a function of the comparison.

28. The receiver of claim 27 wherein the oscillator means comprises a voltage controlled oscillator.

29. The receiver of claim 27 wherein the decoder means comprises a Viterbi decoder.

30. The receiver of claim 29 wherein the Viterbi decoder comprises a zero trace back Viterbi decoder.

31. The receiver of claim 27 wherein the detector means comprises means for comparing a phase of the adjusted first signal with a phase of the multiplied first signal, the tuning means being adapted to tune the reference frequency as a function of a difference in phases.

32. The receiver of claim 27 further comprising a switch between the multiplying means and the decoder means.

33. A method of processing signals having a first and second symbol each representing a constellation point, the first symbol preceding the second symbol in time, the method comprising:

quantizing the first symbol to its nearest constellation point as a function of the first and second signals;

comparing the first symbol to the quantized first symbol; and

adjusting a reference frequency as a function of the comparison.

34. The method of claim 33 further comprising receiving the first and second symbols before the first symbol is quantized.

35. The method of claim 34 further comprising transmitting the signals including the first and second symbols, wherein the receiving of the first and second symbols comprises receiving the transmitted signals.

36. The method of claim 35 wherein the transmission of the signals comprises turbo encoding the first and second symbols before transmission.

37. The method of claim 36 wherein the transmission of the signals comprises interleaving and de-interleaving the turbo encoded signals before transmission.

38. The method of claim 35 wherein the transmission of the signals comprises transmitting a third symbol between the first and second symbols, a first portion of the transmitted signals including the first and second symbols being turbo encoded, and a second portion of the signals including the third signal being turbo encoded and interleaved.

39. The method of claim 38 further comprising receiving the transmitted third symbol between the transmitted first and second symbols, wherein the adjustment of the multiplied first signal is not based on the received third symbol.

40. The method of claim 34 wherein the received first and second symbols are each modulated on a carrier frequency, the method further comprising multiplying each of the first and second symbols with a reference signal having the reference frequency.

41. The method of claim 40 wherein the multiplication of the first and second modulated symbols each comprises recovering the respective symbol by removing the respective carrier frequency.

42. The method of claim 33 wherein the first and second symbols each comprises turbo encoded data.

43. The method of claim 33 wherein the quantization of the first symbol comprises Viterbi decoding the first symbol.

44. The method of claim 33 wherein the comparison of the first symbol with the quantized first symbol comprises detecting a phase difference between the first symbol and the quantized first symbol.

45. The method of claim 45 wherein the adjustment of the reference frequency comprises tuning a voltage controlled oscillator as a function of the phase difference between the first symbol and the quantized first symbol.

46. The method of claim 33 further comprising receiving a third symbol between the first and second symbols, wherein the quantization of the first signal is not based on the received third signal.

47. A receiver to receive a signal including first and second symbols each representing a constellation point, the first symbol preceding the second symbol in time, the receiver comprising:

a decoder to quantize the first symbol as a function of the first and second symbols;
a detector to compare the first symbol to the quantized first symbol; and
an oscillator having a tunable output as a function of the comparison.

48. The receiver of claim 47 wherein the first and second symbols are each modulated on a carrier frequency, the receiver further comprising a multiplier to multiply each of the first and second symbols with the oscillator output to recover its respective symbol by removing its respective carrier frequency.

49. The receiver of claim 47 wherein the decoder comprises a Viterbi decoder.

50. The receiver of claim 47 wherein the detector comprises a phase detector to detect a phase difference between the first symbol and the quantized first symbol.

51. The receiver of claim 47 wherein the oscillator comprises a voltage controlled oscillator.

52. The receiver of claim 47 further comprising a switch positioned in front of the decoder.

53. A communications system, comprising:

a transmitter to transmit a signal including first and second symbols each representing a constellation point, the first symbol preceding the second symbol in time; and

a receiver including a decoder to quantize the first symbol as a function of the first and second symbols, a detector to compare the first symbol to the quantized first symbol, and an oscillator having a tunable output as a function of the comparison.

54. The communications system of claim 53 wherein the transmitter modulates the first and second symbols on a carrier frequency, and the receiver further comprises a multiplier to multiply each of the first and second symbols with the oscillator output to recover its respective symbol by removing its respective carrier frequency.

55. The communications system of claim 54 wherein the decoder comprises a Viterbi decoder.

56. The communications system of claim 54 wherein the detector comprises a phase detector to detect a phase difference between the first symbol and the quantized first symbol.

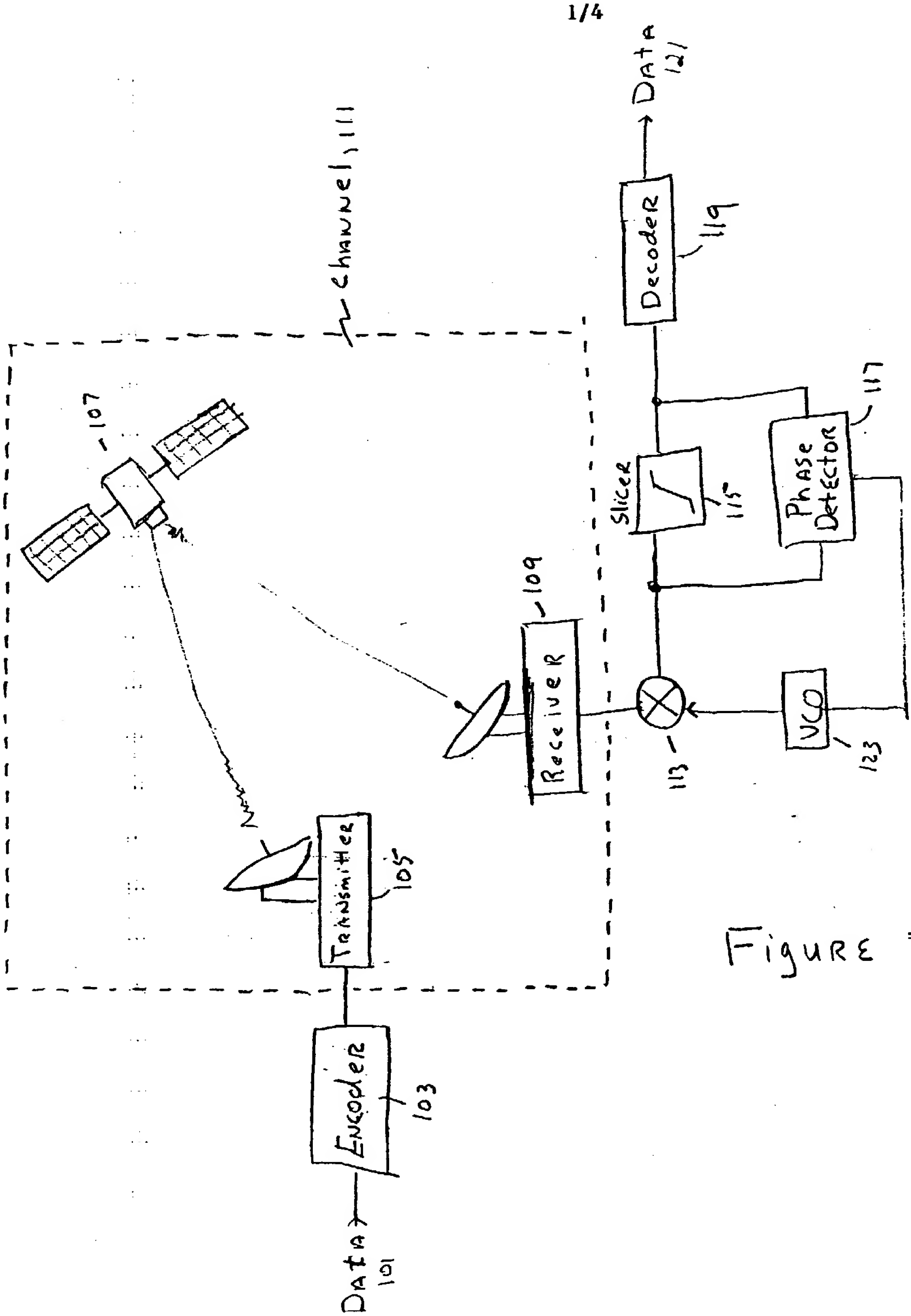
57. The communications system of claim 54 wherein the oscillator comprises a voltage controlled oscillator.

58. The communications system of claim 54 wherein the transmitter further comprises a turbo encoder to turbo encode the signals before transmission to the receiver.

59. The communications system of claim 58 wherein the turbo encoder comprises a trellis encoder to encode a first portion of the signals including the fist and second symbols, and an interleaver coupled to a trellis encoder to process a second portion of the signal.

60. The communications system of claim 59 wherein the receiver further comprises a switch positioned before the decoder to pass only the first portion of the signal to the decoder.

61. The communications system of claim 58 wherein the turbo encoder comprises an interleaver, de-interleaver, and trellis encoder coupled in series to turbo encode the signals before transmission to the receiver.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Encoder
103
Transmitter
105
107
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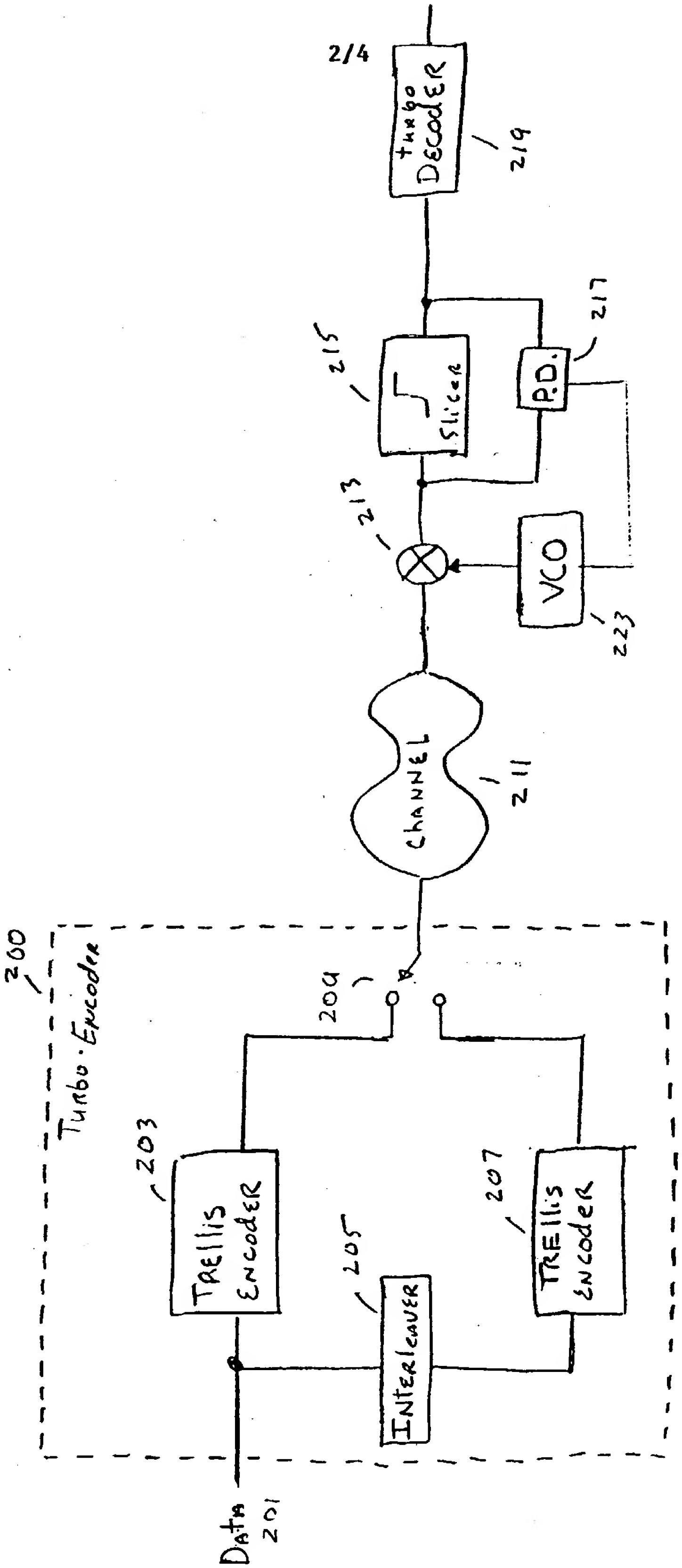
Receiver
109
113
VCO
123
Slicer
115
Phase Detector
117
Decoder
119
Data 121

Figure #1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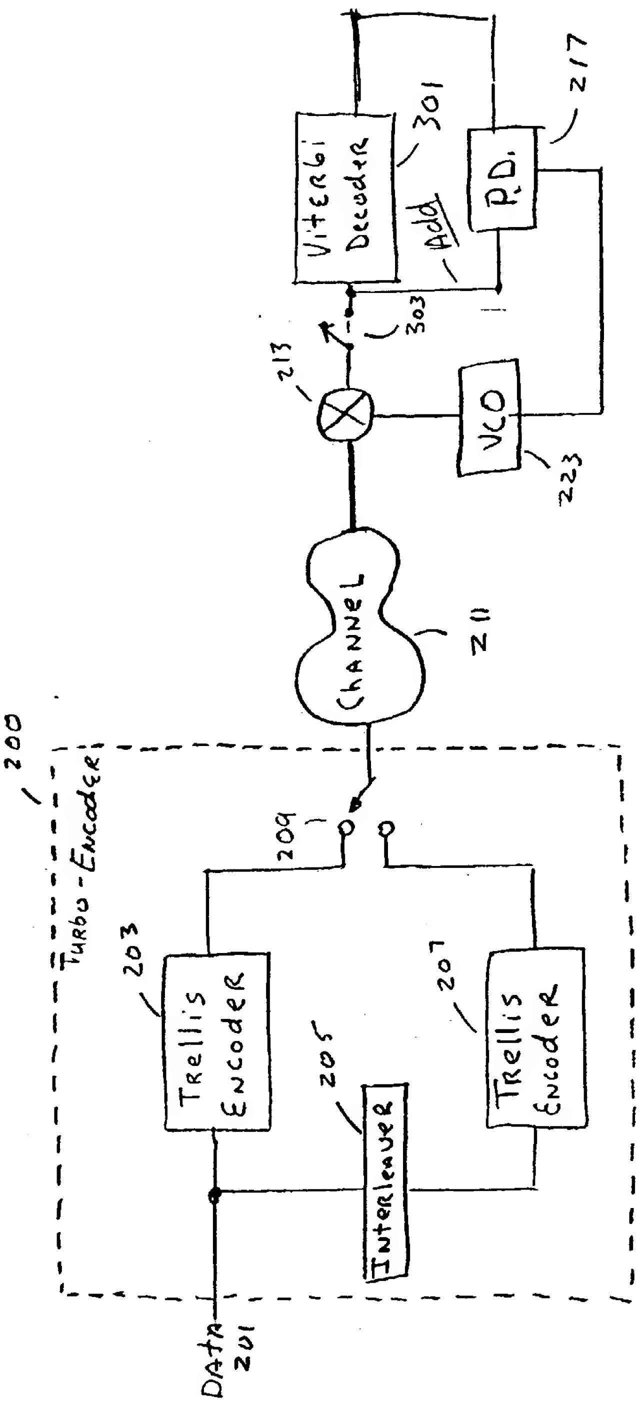
P.D.
217
Turbo Decoder
219

Figure #2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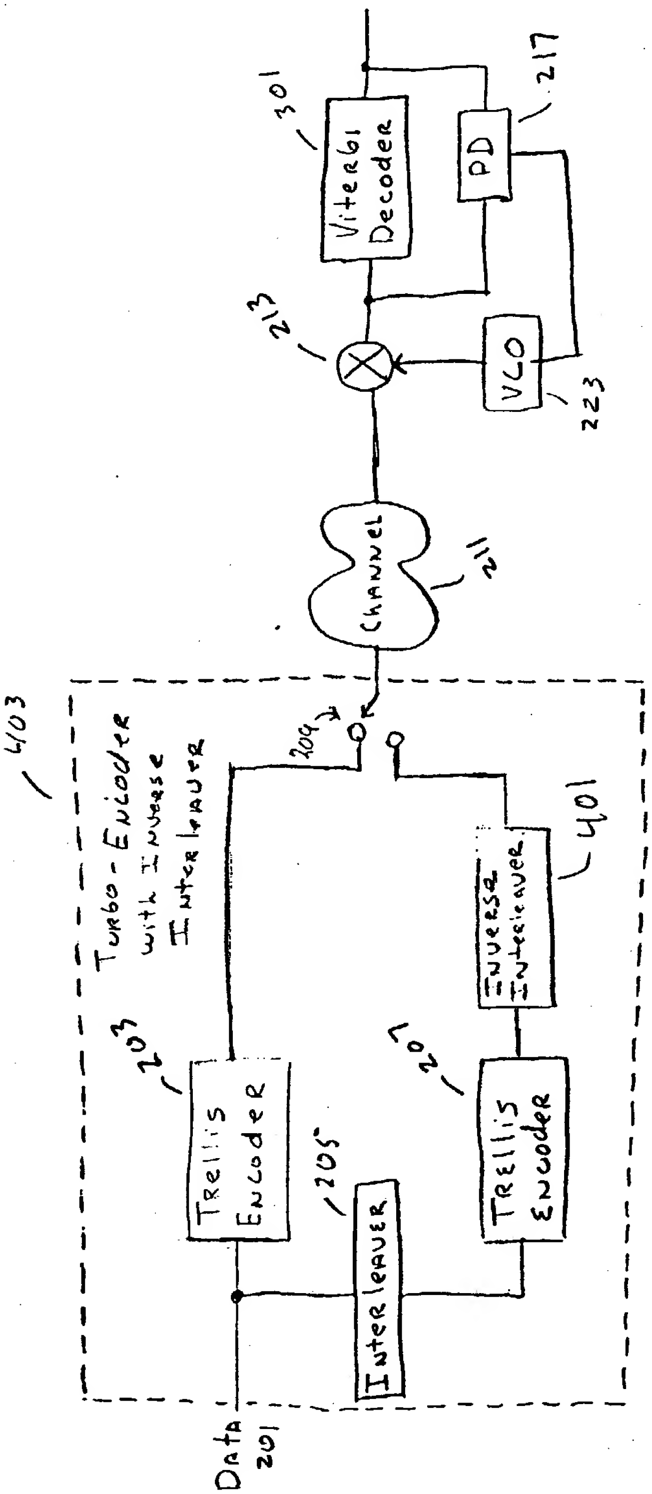
207
Data
201

Figure 3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VCO
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Channel
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Turbo-Encoder with Inverse Interleaver
403
209
401
Inverse Interleaver
Trellis Encoder
203
Trellis Encoder
207
Interleaver
205
Data
201

Figure #4